Lengthening the pedicle of the rectus abdominis myocutaneous flap for repair of upper chest and neck defects

JQ Zhang*, JM Zhang*, WQ Liang, CY Ji, YH Chen

Sun Yat-sen Memorial Hospital, Guangzhou, China

ABSTRACT

INTRODUCTION The aim of this study was to investigate whether the pedicle of the rectus abdominis flap can be lengthened by resecting the inferior costal cartilage segments or associated muscle when repairing upper body defects. A formula was generated that calculates the expected increase in pedicle length.

METHODS Thirty patients underwent computed tomography. The width and thickness of the third to seventh inferior costal cartilage segments as well as the width of the respective intercostal spaces were recorded. Four patients underwent reconstruction of an upper body defect with the relevant flap.

RESULTS The expected mean increases in pedicle length were 4.07cm (standard deviation [SD]: 0.31cm) and 4.63cm (SD: 0.54cm) following resection of the left and right sides respectively of the seventh inferior costal cartilage segment, 7.99cm (SD: 0.49cm) and 10.82cm (SD: 0.23cm) following resection of the left and right sides respectively of the sixth and seventh inferior costal cartilage segments while resection of the fourth to seventh inferior costal cartilage segments would equate to increases of 17.48cm (SD: 0.62cm) and 22.05cm (SD: 0.21cm) for the left and right sides respectively. In four patients who required reconstruction, three flaps survived without problems but one flap developed partial necrosis.

CONCLUSIONS Resecting inferior costal cartilage segments or associated muscle can lengthen the pedicle of the rectus abdominis flap for reconstruction of defects on the upper chest and neck.

KEYWORDS

Internal thoracic artery – Pedicled rectus abdominis flap – Defect repair

Accepted 4 February 2017

CORRESPONDENCE TO

Jinming Zhang, E: jintiannuli545@126.com

In 1906 Tansini first used the latissimus dorsi myocutaneous flap for coverage of radical mastectomy defects.¹ Since then, the chest wall reconstruction technique has evolved and there are now a number of alternatives. Currently, flaps often used in these procedures include the latissimus dorsi, pectoralis major and rectus abdominis flaps.

The rectus abdominis flap has been used extensively as both a pedicled and free flap for chest reconstruction because the technique is simple, it is quick to harvest and is generally reliable.² When repairing upper chest and neck defects, the pedicled rectus abdominis flap is limited by the length of the vascular pedicle, which is restricted by the position of the inferior costal cartilage segments. Evidence suggests that the pedicle of the rectus abdominis flap may be lengthened by resecting the inferior costal cartilage segments.³

This study investigated the hypothesis that resection of the inferior costal cartilage segments or associated muscle can be used to increase the length of the pedicle in patients who are indicated for reconstructive surgery with a pedicled rectus abdominis flap. Lengthening the pedicle would

enable this flap to be used for reconstruction of upper body defects.

The objective of the study was to use imaging to evaluate the width and thickness of the inferior costal cartilage segments as well as the width of the intercostal spaces in order to develop a formula to estimate the expected increase in pedicle length following resection of inferior costal cartilage segments. This paper also presents the clinical details of four patients who underwent reconstruction of an upper body defect with a pedicled rectus abdominis flap following resection of the inferior costal cartilage segments or associated muscle.

Methods

The experimental protocol was established according to the ethical guidelines of the Helsinki Declaration and was approved by the ethics committee of Sun Yat-sen Memorial Hospital in China. Written informed consent was obtained from individual participants.

Imaging

Thirty patients (mean age: 56 years; mean weight: 61.6kg; mean body mass index: 26.7kg/m², range: 24.7–28.9kg/m²) (Table 1) underwent multidetector computed tomography (CT) at our institution between January and December 2013. None of the patients had a previous history of upper abdominal wall surgery and their primary diseases did not include disorders of the ribs, costal cartilage segments, intercostal muscles or pectoral muscles.

Three-dimensional CT angiography was performed with a 64-slice spiral CT scanner (Somatom Sensation 64;

Siemens, Erlangen, Germany). A contrast agent (100ml) was injected into the medial antecubital vein of each patient with a power injector (5ml/s). Each patient received the same dose of radiation (7mSv). Acquisition parameters were: collimation 64 × 0.6mm, rotation time 0.37s, effective tube current 180mAs and tube voltage 120kV.⁴

Images were generated using automated bolus tracking with a scan delay of five seconds. Images were transmitted to a workstation (Siemens). Postprocessing imaging involved volumetric imaging, maximum intensity projection

Table 1 Patient baseline demographics and clinical data

Case	Age / sex	Weight	BMI	Condition	Co-morbidities	Follow-up duration
1	32 F	60.5kg	25.1kg/m ²	Sick sinus syndrome	None	6 mths
2	56 F	62.3kg	26.3kg/m ²	Lung cancer	None	9 mths
3	63 M	65.2kg	24.9kg/m ²	COPD	None	8 mths
4	45 F	54.6kg	26.4kg/m ²	Lung cancer	None	9 mths
5	34 M	71.4kg	24.7kg/m ²	Tracheobronchitis	None	11 mths
6	55 M	70.3kg	26.1kg/m ²	Ulcerative colitis	None	6 mths
7	54 F	56.1kg	25.5kg/m ²	Fracture of humeral shaft	None	10 mths
8	62 M	56.7kg	26.3kg/m ²	COPD	None	12 mths
9	35 F	60.2kg	24.8kg/m ²	Pre-excitation syndrome	None	8 mths
10	71 F	62.4kg	27.6kg/m ²	Tracheobronchitis	None	11 mths
11	39 F	65.7kg	26.5kg/m ²	Lung cancer	None	9 mths
12	46 M	72.1kg	24.9kg/m ²	Lung cancer	None	10 mths
13	49 M	59.8kg	27.3kg/m ²	Middle lobe syndrome	None	6 mths
14	50 F	57.1kg	25.5kg/m ²	Lung cancer	None	12 mths
15	52 M	61.2kg	27.9kg/m ²	Rheumatic carditis	None	8 mths
16	53 M	57.9kg	25.0kg/m ²	Lung cancer	None	11 mths
17	57 M	57.3kg	28.1kg/m ²	Benign tumour	None	9 mths
18	48 F	71.3kg	25.6kg/m ²	Duodenal ulcer	None	6 mths
19	59 F	67.2kg	25.1kg/m ²	Lung cancer	None	10 mths
20	65 M	56.8kg	26.9kg/m ²	Upper respiratory tract infection	None	12 mths
21	71 F	69.9kg	28.3kg/m ²	Lung cancer	None	8 mths
22	63 F	61.6kg	28.9kg/m ²	Benign tumour	None	11 mths
23	72 M	58.9kg	26.9kg/m ²	COPD	None	10 mths
24	58 F	59.9kg	25.7kg/m ²	Valvular heart disease	None	8 mths
25	56 F	49.8kg	28.6kg/m ²	Lung cancer	None	12 mths
26	56 M	61.5kg	25.2kg/m ²	Bronchogenic cyst	None	6 mths
27	61 M	60.0kg	28.8kg/m ²	Fracture of femoral neck	None	8 mths
28	60 F	58.7kg	25.8kg/m ²	Lung cancer	None	12 mths
29	64 F	69.8kg	25.9kg/m ²	Coronary artery disease	None	8 mths
30	57 F	57.0kg	25.3kg/m ²	Lung cancer	None	11 mths

BMI = body mass index; COPD = chronic obstructive pulmonary disease

and multiplanar reconstruction. Reconstructed images of the transverse, sagittal and coronal sections were evaluated.

The width and thickness of the third to seventh inferior costal cartilage segments as well as the width of the respective intercostal spaces were measured and recorded (Figs 1 and 2). A formula for calculating the expected increase in pedicle length following resection of the third, fourth, fifth, sixth and seventh inferior costal cartilage segments was developed.

Case studies

This paper also presents four case studies of patients who underwent reconstruction of an upper body defect with a pedicled rectus abdominis flap following inferior costal cartilage or associated muscle resection.

Results

Imaging study

The mean width and thickness of the third, fourth, fifth, sixth and seventh inferior costal cartilage segments are shown in Table 2, and the mean width of the respective intercostal spaces in Table 3. The portion of the pedicle that passes down through the inferior costal cartilage does not contribute to the overall length of the pedicle. This length is compensated for by the thickness of the upper costal cartilage. When the flap traverses the ipsilateral/opposite defect on the chest, the sum of the width of the costal cartilage and the width of the intercostal space must be multiplied by two. Consequently, the increase in pedicle length was calculated from the formula

$$(a + b) \times 2 + (c1 - c2)$$

where a is the width of the costal cartilage, b is the width of the intercostal space, $c1$ is the thickness of the costal cartilage segment and $c2$ is the thickness of the upper costal cartilage (Fig 2).

The muscle covering every inferior costal cartilage segment was assumed to be of equal thickness. Applying the formula above, therefore, the expected mean increases in pedicle length following resection of the various costal cartilage segments were calculated (Table 4). The increases were 4.07cm (standard deviation [SD]: 0.51cm) and 4.63cm (SD: 0.54cm) following resection of the left and right sides respectively of the seventh inferior costal cartilage segment while resection of the fourth to seventh inferior costal cartilage segments would equate to increases of 17.48cm (SD: 0.62cm) and 22.05cm (SD: 0.21cm) for the left and right sides respectively.

Clinical study

Four patients underwent reconstruction of an upper body defect with a pedicled rectus abdominis flap following inferior costal cartilage or associated muscle resection. The mean dimension of the flaps was 26cm (SD: 0.1cm) $\times$ 13cm

Table 2 Mean width and thickness of the third to seventh inferior costal cartilage segments as well as the expected increase in pedicle length

	Costal cartilage width		Costal cartilage thickness	
	Left side	Right side	Left side	Right side
3rd	0.96cm (SD: 0.19cm)	1.10cm (SD: 0.22cm)	0.61cm (SD: 0.11cm)	0.71cm (SD: 0.25cm)
4th	1.03cm (SD: 0.11cm)	1.22cm (SD: 0.50cm)	0.79cm (SD: 0.14cm)	0.84cm (SD: 0.11cm)
5th	1.12cm (SD: 0.54cm)	1.39cm (SD: 0.33cm)	0.92cm (SD: 0.18cm)	1.00cm (SD: 0.27cm)
6th	1.37cm (SD: 0.35cm)	1.49cm (SD: 0.30cm)	0.72cm (SD: 0.19cm)	0.73cm (SD: 0.20cm)
7th	1.40cm (SD: 0.39cm)	1.58cm (SD: 0.47cm)	0.57cm (SD: 0.14cm)	0.70cm (SD: 0.20cm)
SD = standard deviation				

Table 3 Mean width of the intercostal spaces

	Left side	Right side
3rd	1.37cm (SD: 0.45cm)	1.42cm (SD: 0.38cm)
4th	1.07cm (SD: 0.59cm)	1.36cm (SD: 0.87cm)
5th	0.69cm (SD: 0.17cm)	0.74cm (SD: 0.21cm)
6th	0.71cm (SD: 0.31cm)	0.75cm (SD: 0.34cm)
SD = standard deviation		

Table 4 Expected mean increase in pedicle length following resection of costal cartilage segments

	Left side	Right side
7th	4.07cm (SD: 0.31cm)	4.63cm (SD: 0.54cm)
6th and 7th	7.99cm (SD: 0.49cm)	10.82cm (SD: 0.23cm)
5th, 6th and 7th	12.50cm (SD: 0.53cm)	16.64cm (SD: 0.62cm)
4th, 5th, 6th and 7th	17.48cm (SD: 0.62cm)	22.05cm (SD: 0.21cm)
SD = standard deviation		

(SD: 0.2cm). Three flaps survived without problems but one flap developed partial necrosis. All donor sites healed completely.

Case 1: A 71-year-old woman had a mastectomy owing to cancer in her left breast. Radiotherapy resulted in a left supraclavicular ulcer. The ulcer was completely resected and the resultant 30cm × 8cm upper body defect was reconstructed with a 29cm × 12cm pedicled rectus abdominis flap. A 3cm × 1.6cm × 0.7cm (length × width × thickness) portion of the seventh inferior costal cartilage segment was resected, which increased the length of the pedicle by 4.8cm. The flap completely covered the defect. At three

months following surgery, the flap had survived and the donor site had healed (Fig 5).

Case 2: A 63-year-old woman had a mastectomy owing to cancer in her right breast. Radiotherapy resulted in an ulcer in her left chest wall. The ulcer was completely resected and the resultant 19cm × 17cm upper body defect was reconstructed with a 20cm × 18cm pedicled rectus abdominis flap. The muscle superior to and covering the seventh costal cartilage segment was resected to increase the length of the pedicle. The flap completely covered the defect. At three months, the flap had survived and the donor site had healed (Fig 4).

Case 3: A 61-year-old man had throat surgery because of tumour recurrence on the right side of his neck, four months after receiving treatment for left laryngeal carcinoma. The tumour was completely resected and the resultant 27cm × 6.5cm upper body defect was reconstructed with a 27cm × 7cm pedicled rectus abdominis flap. A 2cm × 1.4cm × 0.6cm (length × width × thickness) portion of the seventh inferior costal cartilage segment was resected, which increased the length of the pedicle by 5.2cm. The flap completely covered the defect. At three months, the flap had survived and the donor site had healed (Fig 5).

Case 4: A 67-year-old man was suffering from recurrence of oesophageal cancer. The tumour was completely resected and the resultant 27cm × 6.5cm upper body defect was reconstructed with a 27cm × 7cm pedicled rectus abdominis flap. A 2cm × 1.4cm × 0.6cm (length × width × thickness) portion of the seventh inferior costal cartilage segment was resected, which increased the length of the pedicle by 5.2cm. The postoperative outcome was good. However, the distal part of the flap developed necrosis and required a further operation. During the second round of surgery, a 1.8cm × 1.1cm × 0.2cm (length × width × thickness) portion of the sixth inferior costal cartilage segment was resected. The length of the pedicle was increased by 2cm. A surplus portion of the flap was elevated to completely cover the defect. At three months, the flap had survived and the incision in the abdominal wall had healed (Fig 6).

Figure 3 Case 1: (A) Preoperative image showing a left supraclavicular ulcer. (B) The ulcer was resected, leaving a 30cm × 8cm upper body defect. A right rectus abdominis flap measuring 29cm × 12cm was designed. The flap was incised and resected to the costal margin. A 3cm × 1.6cm × 0.7cm (length × width × thickness) portion of the seventh inferior costal cartilage segment was resected. The flap was transferred from the right side to repair the defect. The length of the pedicle was increased by 4.8cm so the flap completely covered the defect. (C) At three months, the flap had survived and the incision in the abdominal wall had healed.

Figure 4 Case 2: (A) Preoperative image showing an ulcer in the right chest wall. (B) The ulcer was resected, leaving a 19cm × 17cm upper body defect. A right rectus abdominis flap measuring 20cm × 18cm was designed. The flap was incised and resected to the costal margin. The muscle superior to and covering the seventh costal cartilage was resected so the flap completely covered the defect. (C) At three months, the flap had survived and the incision in the abdominal wall had healed.

Figure 5 Case 3: (A) Preoperative image showing a right laryngeal carcinoma. (B) The tumour was resected, leaving a 27cm × 6.5cm upper body defect. A right rectus abdominis flap measuring 27cm × 7cm was designed. The flap was incised and resected to the costal margin. A 2cm × 1.4cm × 0.6cm (length × width × thickness) portion of the seventh inferior costal cartilage segment was resected. (C) At three months, the flap had survived and the incision in the abdominal wall had healed.

Discussion

Our unit has extensive clinical experience of tissue defects and organ reconstruction following breast cancer and cervical oesophageal resection using pedicled and free rectus abdominis flaps. Consequently, we understand the advantages and disadvantages of each flap.

The pedicled rectus abdominis flap is used widely for repairing defects but the need for a long pedicle prohibits its application for the reconstruction of upper chest and neck defects. The length of the pedicle is limited by the location of

the inferior costal cartilage. Resection of the inferior costal cartilage segments may remove this restriction, lengthen the pedicle and allow the pedicled rectus abdominis flap to be used as a reconstruction option for upper body defects.⁵ In addition, an intercostal nerve must be divided to mobilise the pedicle; the injured nerve may cause hypoesthesia or delayed sensory recovery. Notably, in patients with contraindications that include old abdominal scars and long-term smoking history, for example, the free rectus abdominis flap remains the more suitable option.⁵

Currently, free transverse rectus abdominis myocutaneous (TRAM) flaps⁶ and deep inferior epigastric perforator (DIEP) flaps⁷ are used for reconstruction of upper chest and neck defects. The free TRAM flap is associated with postoperative flap thrombosis rates of 2–5%⁸ and partial flap loss is common. In such cases, partial flap loss is usually treated with dressing changes and wound contracture. Fat necrosis can be caused by a permanent firm suture in the margin that requires further resection. The DIEP flap is associated with much higher rates of postoperative flap necrosis than the pedicled rectus abdominis myocutaneous flap as the diameter of the nutrient vessels of the skin flap are thinner.^{9,10}

The choice of a free or pedicled rectus abdominis flap for reconstruction of upper chest and neck defects is determined by cost, operative time and skill of the operating surgeon. According to Pien *et al*, based on data from 2009 to 2011, the mean cost per flap was \$15,538 for a pedicled TRAM flap, \$20,756 for a free pedicled TRAM flap and \$23,616 for a DIEP flap.¹¹ Compared with a free TRAM flap and DIEP flap, the pedicled TRAM flap is associated with lower costs.

In China, patients are responsible for the majority of costs associated with medical procedures. Defects in the upper chest and neck most often arise from radiotherapy after breast cancer or craniomaxillofacial regional cancer. Cancer treatment represents a substantial financial burden for the patient. Chest and neck reconstruction with a free rectus abdominis flap requires a dexterous surgeon, advanced microinstruments and a long time in theatre; it is therefore a costly procedure. Furthermore, cancer patients may not be suitable candidates for free rectus abdominis flaps because radiotherapy can damage recipient vessels.

Pedicled rectus abdominis flaps are an economically viable option as they require less advanced microinstruments and less skilled surgeons. However, pedicled flaps derive their blood supply from the superior epigastric artery, which is unreliable owing to its small vessel diameter and inadequate perfusion rate. The rate of significant fat necrosis of the flap (>10% of the flap volume) has been reported as 10.6%.¹² The blood supply can be augmented by: ‘supercharging’ using the inferior epigastric vessels; microsurgical anastomosis in the area of the defect, which significantly increases blood supply and venous return;^{13,14} using a bipedicle flap;¹⁵ or ligating the superior and deep inferior epigastric vessels two weeks prior to reconstruction, in order to increase arterial pressure and decrease venous congestion.¹⁶ Moreover, a long vascular pedicle is associated with postoperative necrosis.

Upper body defect repair was performed at our institution in four patients using a pedicled rectus abdominis flap following resection of costal cartilage or associated muscle. The patients included a woman with a supraclavicular ulcer, a woman with an ulcer on her left chest, a man with a defect on his neck and a man with a defect at the right mastoid. Under normal circumstances, pedicled rectus abdominis flaps would not completely cover these defects. Resection of the seventh inferior costal cartilage segment or the muscle superior to and covering the seventh costal cartilage segment lengthened the pedicles, enabling use of a pedicled rectus abdominis flap for reconstruction.

Postoperatively, three flaps survived without problems. In one case, suturing the skin on the pedicle compressed the blood supply of the flap and the distal part of the flap became necrotic. During a second operation, the sixth inferior costal cartilage segment was resected and the surplus portion of the flap was elevated to cover the defect. Following this procedure, the flap survived without further problems. The aesthetic effect in all cases was comparable with reconstruction using a free rectus abdominis flap.

Currently, we would recommend this surgical technique for the reconstruction of defects that occur on the upper body where the inferior costal cartilage segments limit pedicled rectus abdominis flap transposition and perfusion. Nevertheless, this recommendation is based on our assessment of stability of the chest wall and donor site morbidity over a relatively short follow-up period.

The stability of the chest wall must be maintained following resection of the inferior costal cartilage segments. During microtia reconstruction with autogenous costal cartilage, donor site deformity is prevented by total

subperichondrial costal cartilage harvest, costochondral growth centre preservation, donor site reconstitution with morselised leftover costal cartilage and perichondrial repair.¹⁷ Consequently, when resecting the inferior costal cartilage segments to increase the length of the pedicle of a rectus abdominis flap, we suggest the stability of the chest wall may be maintained using prosthetics made from materials such as polypropylene mesh,¹⁸ Composix™ E/X mesh (Bard, Murray Hill, NJ, US)¹⁹ or acellular dermal matrices.²⁰

In our clinical experience, however, we have not attempted to stabilise the chest wall with these methods during upper chest and neck defect reconstruction with a pedicled rectus abdominis flap as only a small portion of costal cartilage was resected. Indeed, none of our patients experienced any adverse sequelae associated with chest instability during the three months of postoperative follow-up. Further research is needed to elucidate the extent of costal cartilage resection that requires replacement with a prosthetic.

Notably, when the flap is harvested by excision of the rectus abdominis muscle, abdominal complications such as hernia or bulge could arise.²¹ There are various reasons for this. The traditional view is that the rectus abdominis muscle maintains tension in the abdominal wall and that this function can be maintained even after 30% of the muscle has been excised.²² More recently, it has been suggested that it is the rectus abdominis anterior sheath that maintains tension in the abdominal wall. Accordingly, Kroll proposed that fascial closure should be used at the donor site.²³ In our patients, the shape of the pedicle rectus abdominis flap meant it was possible to resect a smaller area of the rectus abdominis muscle than would have been necessary for a conventional TRAM flap. Consequently, two methods were used to decrease donor site morbidity.

First, we minimised excision of the rectus abdominis muscle to preserve the blood supply to the flap. The superior epigastric artery is directly derived from the internal thoracic artery, and provides multiple muscle perforators that travel through the rectus abdominis muscle and 4–6 perforators (0.4–0.8mm in diameter) that supply blood to the abdominal skin.²⁴ When performing flap graft surgery, we locate and preoperatively mark the perforators on the rectus abdominis muscle with multidetector CT. The perforators are stripped carefully to minimise damage. Second, we sutured a hernia patch to close the rectus abdominis anterior sheath. This results in less short-term donor site morbidity. The implication of this technique on long-term donor site morbidity warrants further research.

This study was limited by selection bias. The patients chosen for our case series tended to be those with defects that had a better basal blood supply as resecting the costal cartilage and creating the long pedicle is associated with blood loss. For defects with insufficient blood supply, the postoperative outcome of lengthening the pedicle of the rectus abdominis myocutaneous flap is equivalent to using a free skin flap. In addition, patients with weak abdominal muscles are contraindicated for this kind of surgery as they have high donor site morbidity. Furthermore, patient status must be assessed comprehensively and preoperative

decisions must be considered carefully when choosing to lengthen the pedicle by resecting the costal cartilage or associated muscle. In patients with old abdominal scars and a long history of smoking, the free rectus abdominis flap remains the more suitable option.

Conclusions

The inferior costal cartilage segments are the main factors that restrict rotation and perfusion of pedicled rectus abdominis flaps. We suggest that resection of the inferior costal cartilage segments or associated muscle can be used to increase the length of the pedicle in most patients who are suitable for reconstructive surgery with a pedicled rectus abdominis flap. Lengthening the pedicle enables this flap to be used for reconstruction of upper body defects.

Acknowledgements

This work was supported by grants from the Key Laboratory of Malignant Tumour Molecular Mechanism and Translational Medicine of Guangzhou Bureau of Science and Information Technology, and from the Key Laboratory of Malignant Tumour Gene Regulation and Target Therapy of Guangdong Higher Education Institutes.

References

1. Bakri K, Mardini S, Evans KK *et al*. Workhorse flaps in chest wall reconstruction: the pectoralis major, latissimus dorsi, and rectus abdominis flaps. *Semin Plast Surg* 2011; **25**: 43–54.
2. Tukiainen E. Chest wall reconstruction after oncological resections. *Scand J Surg* 2013; **102**: 9–13.
3. Zenn MR, Heitmann C. Extended TRAM flap: feasibility study on fresh human cadavers. *Ann Plast Surg* 2003; **50**: 256–262.
4. Rozen WM, Ashton MW, Grinsell D *et al*. Establishing the case for CT angiography in the preoperative imaging of abdominal wall perforators. *Microsurgery* 2008; **28**: 306–313.
5. Schefflan M, Dinner MI. The transverse abdominal island flap: part I. Indications, contraindications, results, and complications. *Ann Plast Surg* 1983; **10**: 24–35.
6. Avraham T, Clavin N, Mehrara BJ. Microsurgical breast reconstruction. *Cancer J* 2008; **14**: 241–247.
7. Parrett BM, Caterson SA, Tobias AM, Lee BT. DIEP flaps in women with abdominal scars: are complication rates affected? *Plast Reconstr Surg* 2008; **121**: 1,527–1,531.
8. Kroll SS. Fat necrosis in free transverse rectus abdominis myocutaneous and deep inferior epigastric perforator flaps. *Plast Reconstr Surg* 2000; **106**: 576–583.
9. Cordeiro PG. Breast reconstruction after surgery for breast cancer. *N Engl J Med* 2008; **359**: 1,590–1,601.
10. Hartrampf CR, Bennett GK. Autogenous tissue reconstruction in the mastectomy patient. A critical review of 300 patients. *Ann Surg* 1987; **205**: 508–519.
11. Pien I, Caccavale S, Cheung MC *et al*. Evolving trends in autologous breast reconstruction: is the deep inferior epigastric artery perforator flap taking over? *Ann Plast Surg* 2016; **76**: 489–493.
12. Paige KT, Bostwick J, Bried JT, Jones G. A comparison of morbidity from bilateral, unipedicled and unilateral, unipedicled TRAM flap breast reconstructions. *Plast Reconstr Surg* 1998; **101**: 1,819–1,827.
13. Yamamoto Y, Nohira K, Shintomi Y *et al*. 'Turbo charging' the vertical rectus abdominis myocutaneous (turbo-VRAM) flap for reconstruction of extensive chest wall defects. *Br J Plast Surg* 1994; **47**: 103–107.
14. Pernia LR, Miller HL, Saltz R, Vasconez LO. 'Supercharging' the rectus abdominis muscle to provide a single flap for cover of large mediastinal wound defects. *Br J Plast Surg* 1991; **44**: 243–246.

15. Li S, Mu L, Li Y *et al*. Breast reconstruction with the free bipedicle inferior TRAM flap by anastomosis to the proximal and distal ends of the internal mammary vessels. *J Reconstr Microsurg* 2002; **18**: 161–168.
16. Codner MA, Bostwick J, Nahai F *et al*. TRAM flap vascular delay for high-risk breast reconstruction. *Plast Reconstr Surg* 1995; **96**: 1,615–1,622.
17. Wallace CG, Mao HY, Wang CJ *et al*. Three-dimensional computed tomography reveals different donor-site deformities in adult and growing microtia patients despite total subperichondrial costal cartilage harvest and donor-site reconstruction. *Plast Reconstr Surg* 2014; **133**: 640–651.
18. Noda M, Endo C, Hosaka T *et al*. Dedifferentiated chondrosarcoma of the chest wall: reconstruction with polypropylene mesh using a transverse rectus abdominis myocutaneous flap. *Gen Thorac Cardiovasc Surg* 2011; **59**: 199–201.
19. Osawa H, Nishii T, Suzuki Y *et al*. Experience of chest wall reconstruction with newly developed material. *Kyobu Geka* 2008; **61**: 1,023–1,025.
20. Sodha NR, Azoury SC, Sciortino C *et al*. The use of acellular dermal matrices in chest wall reconstruction. *Plast Reconstr Surg* 2012; **130**(5 Suppl 2): 175S–182S.
21. Pinell-White XA, Kapadia SM, Losken A. The management of abdominal contour defects following TRAM flap breast reconstruction. *Aesthet Surg J* 2014; **34**: 264–271.
22. Kroll SS, Schusterman MA, Reece GP *et al*. Abdominal wall strength, bulging, and hernia after TRAM flap breast reconstruction. *Plast Reconstr Surg* 1995; **96**: 616–619.
23. Kroll SS. Midline fascial preservation in double-pedicle TRAM flap breast reconstruction. *Ann Plast Surg* 1989; **23**: 104–111.
24. Karunanithy N, Rose V, Lim AK, Mitchell A. CT angiography of inferior epigastric and gluteal perforating arteries before free flap breast reconstruction. *Radiographics* 2011; **31**: 1,307–1,319.